DOE/OR/22088--5

U.S. FISH AND WILDLIFE SERVICE
Pacific Islands Office, Ecological Services

SURVEYS OF DISTRIBUTION AND ABUNDANCE OF THE HAWAIIAN HAWK WITHIN THE VICINITY OF PROPOSED GEOTHERMAL PROJECT SUBZONES IN THE DISTRICT OF PUNA, HAWAI'I

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Final Report
August 1994

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INTRODUCTION

In 1993, the U.S. Fish and Wildlife Service (USFWS) entered an interagency agreement with the Department of Energy (DOE) to conduct specific biological surveys to identify potential impacts of proposed geothermal development on the biota of the east rift zone of Kilauea volcano in the Puna district on the island of Hawai`i (Figure 1). This report presents data on the distribution, habitat use, and density of the Hawaiian hawk or `Io (*Buteo solitarius*).

Data were collected by the USFWS to assess the potential impacts of geothermal development on `Io populations on the island of Hawai`i. These impacts include degradation of potential nesting habitat and increased disturbance due to construction and operation activities. Data from these surveys were analyzed as part of an island wide population assessment conducted by the Western Foundation of Vertebrate Zoology (Morrison *et al.* 1994) at the request of the USFWS.

Species Background

The `Io is a small broad-winged hawk endemic to the Hawaiian Islands. It occurs in light and dark color phases (morphs), but there is a wide range of intermediate coloration. The adult light phase birds have a dark brown head and back. The underside is white with some brown streaking on the belly and upper chest. Immature light phase birds are paler, having a buff white head and chest. Dark phase adults and immatures are completely dark brown, with some mottling on the head and chest of the immature birds. Juvenile birds of both color phases have blue-green legs, feet, and cere (fleshy area around the bill). Adult ceres are bright yellow and the legs and feet pale yellow. Like most raptors, females are larger than males. The `Io was listed as endangered in 1967 (USFWS 1984). A recovery plan was prepared by C.R. Griffin (USFWS 1984).

Griffin (1985) conducted detailed studies of the basic biology of the `Io. `Io build large nests (65 cm in diameter) that are used for many years. Of 28 nests that he found, 17 were in `ohi`a trees (*Metrosideros polymorpha*), 3 in koa trees (*Acacia koa*) and 8 in exotic-dominated vegetation. He concluded that nest sites were chosen based more on the availability of trees rather than species; `ohi`a trees being more common than other tree species. He found no difference in nesting success between areas dominated by native versus exotic vegetation.

Average clutch size is one egg with an incubation period averaging 38 days and the nestling period 59-63 days. Males assist with incubation and provide most of the food during the nestling period. Females brood the chicks. The nesting period lasts from early spring until late summer, when the chicks fledge. Adults continue to feed the juveniles 25 to 37 weeks after fledging. `Io do not breed every year; Griffin (1985) found that adults which breed successfully tend to nest in alternate years.

`Io aggressively defend territories and nests. They remain in the same territory (with the same mate) for life as do many other tropical hawk species (Faaborg *et al.* 1980, Mader 1982). Radio telemetry data collected by Griffin (1985) showed overlapping home ranges and dramatic differences in home range use between the breeding and non-breeding season. Of eight birds he tracked, territory size averaged 447 ha (206 acres). Females showed larger home ranges, especially outside of the breeding season. One female showed the largest home range of 768 ha (353 acres). One male, whose territory encompassed papaya and guava fields, had an especially small territory of only 48 ha (22 acres).

Records of `Io sightings exist from all the islands, but the bird is known to nest only on the island of Hawai`i, where it has been observed in all districts at various elevations (Banko 1980; USFWS 1984). Most museum specimens were collected in Ola`a and Kea`au in the Puna District between 1898-1900. For the location of places named in the text, refer to the reference map (Figure 2).

Hawks were sighted regularly in the area near Makaopuhi and Napau Craters in Hawai`i Volcanoes National Park from the late 1930's through the 1970's (Banko 1980). Conant (1980) conducted bird surveys in the Kalapana Extension of the Park from 1976-1979 and recorded `Io as being uncommon (<1 bird/40 ha; <1 bird/100 acres), estimating just two or three breeding pairs present in the study area. Birds were seen most frequently at Puaialua Crater, just south of Napau Crater, and in closed `ohi`a forest near the eastern boundary of the Extension (Conant 1980). Banko (1980) summarized twelve records of `Io in the Kalapana area of Hawai`i Volcanoes National Park between 1941 and 1974. Elsewhere in the Puna district Banko's records note the presence of `Io from 1939 to 1973. Sightings occurred between Kea`au and Lava Tree State Park, near Pahoa, near Kapoho, southwest of Pohoiki, Isaac Hale Beach Park, Green Lake in Kapoho Crater, on the Hilo side of Pahoa, and at Honolulu Landing (Banko 1980).

`Io were found throughout the study area during the Hawai`i Forest Bird Survey, but population densities were not calculated (Scott *et al.* 1986; Jacobi 1985). `Io were seen in Wao Kele O Puna Natural Area Reserve (now Campbell Estate land) on two different transects (USFWS 1979).

The Nature Conservancy (TNC) has compiled more recent `Io sightings in the Puna District, many from Griffin's nest observations in the early 1980's (TNC Hawai`i Natural Heritage Database 1993). Two nests, each with two adults and a chick, were found at the UH Experiment Station, and two more were observed in Leilani Estates and nearby Pu`u Kaliu. A number of nests were watched near the south boundary of the Kahaualea Natural Area Reserve, Royal Gardens subdivision, in an area that has since been covered by lava. Nest observations were also conducted at a nest with two young near Kaualeau on Kamaili Road.

`Io populations are thought to have undergone a long-term decline in numbers, although they occupy the same range today as they did historically (Banko 1980, Griffin 1985). Unlike the majority of Hawai`i's native birds, `Io are more tolerant of habitat alteration and avian diseases. The greatest threat to `Io populations according to Griffin (1985; Baskett and Griffin 1983) is human disturbance. Griffin recommended continuation of population surveys, monitoring nesting success, habitat protection, and prevention of detrimental human-`Io interactions especially during the breeding season.

OBJECTIVES

Current information on the distribution and abundance of `Io within the vicinity of the Geothermal Project was needed to assess the potential impacts of geothermal development on `Io populations found within this area.

The following objectives were identified at the outset of this project:

1) determine the presence/absence and distribution of `Io within the project area;

2) determine population size of hawks in the Puna area;

3) locate territories and/or breeding sites;

4) evaluate potential negative impacts or limiting factors on the species detected within the vicinity of geothermal resource subzones;

5) identify habitat characteristics of areas used by hawks.

Population estimates in Puna were calculated for areas accessible by road. Due to time constraints, surveys for the present project were conducted primarily outside of the `Io breeding season, so objective 3 was not accomplished. Land access was restricted in much of the subzones; therefore, objectives 1 and 2 were not carried out for all the project areas. We recommend completion of these objectives for a final EIS.

METHODS

Hawaiian hawk surveys were conducted between 20 December 1993 and 27 January 1994 along road transects in the Puna district in conjunction with an island-wide survey of this species funded by the U.S. Fish and Wildlife Service (Figure 3). Each transect was surveyed five times by two observers during that period. Point counts were performed between 0830 and 1700 hours. Transect 1 (upper Puna) contained 20 survey points and transect 2 (lower Puna) had 21 survey points. Points were spaced approximately 3.2 kilometers (2 miles) apart; each point was located in an area

that provided a clear view of the vicinity in order to better observe `Io. Vocalization playbacks were used to elicit responses from `Io in the area. Counts lasted ten minutes at each point. `Io vocalization recordings were broadcast for one minute at high volume using a megaphone. Observers listened and watched for `Io for seven more minutes. This was followed by another minute of vocalization playback and one more minute of observation. If an `Io responded to the tape, by vocalizing or approaching, the tape was stopped. Counts were stopped during heavy rain or high winds. Incidental `Io sightings were also recorded during seabird, bat, forest bird, and botanical surveys. Incidental sightings from August 1993 through January 1994 are included in this report.

Rain level (0-4), wind speed (0-4), temperature (*C), cloud cover (%) and vegetation associations adapted from Jacobi (1989) were noted at each point. For each hawk detected, the following information was recorded: distance (in m) from observer; detection mode (visual, auditory, or both); age (immature, adult, unknown); sex (male, female, unknown); and color morph (light, dark, unknown). Hawks' responses to playbacks were also noted.

Statistical analyses for `Io surveys island wide were conducted by Morrison *et al.* (1994) using the program DISTANCE (Laake *et al.* 1993). Information from the analysis pertaining to the Puna district was used for the purposes of this environmental impact assessment.

RESULTS

`Io surveys conducted on approximately 132 km (82 miles) of roads throughout Puna resulted in 27 hawk detections (Table 1). Based on repeated hawk sightings and average territory sizes, we estimate the actual number of individual hawks sighted to be between 13 and 27 within the area surveyed. The locations of `Io detections during playback surveys conducted from December 1993 - January 1994 are given in Figure 3. Density estimates summarized by transect were calculated at .001 hawks/ha for the upper Puna transects, and .002 hawks/ha for the lower Puna transects. Combined estimate for both transects was .001 hawks/ha (Table 2). The total area surveyed was estimated at 48,823 ha (122,057 acres).

If all of the survey area was considered suitable `Io habitat, total hawks from the study area would be estimated at 48 individual hawks based on density estimates reported by Morrison *et al.* (1994) across all vegetation types. However, although hawks occurred in a variety of habitat types, `Io sightings were not uniformly distributed during our survey efforts (Figure 3).

A total of 56 incidental `Io sightings was also recorded in Puna from August 1, 1993 - January 27, 1994 (Table 3). Hawks occurred in native, mixed and exotic-dominated vegetation. Although systematic surveys were only conducted between 0830 and

1700 hours., incidental sightings were recorded from 0600 until 1910. The locations for incidental `Io sightings are shown on Figure 4.

DISCUSSION

Although 27 survey detections and 56 incidental `Io detections were made, the actual number of hawks seen is uncertain due to repeated survey effort on different dates. The variability in territory size and home range boundaries makes it impossible to know if hawks occur at more than one point during surveys conducted over time.

The density estimates of `Io from the Puna District can be compared to density estimates from surveys conducted island wide during the same time period. `Io densities in Puna based on extensive surveys were .001 hawks/ha. (Morrison *et al.* 1994). Island wide road surveys had an overall density estimate of .002 hawks/ha. Conant's 1980 estimate for the hawk densities in the Kalapana extension was also .002 hawks/ha. These density estimates in Puna are substantially lower than intensive survey estimates of .004 hawks/ha (Morrison *et al.* 1994) and .005 hawks/ha in 1985 by Griffin of the entire island.

Population estimates of the `Io from the Puna District can also be compared to population estimates conducted island wide. We estimated the `Io population of our study area in Puna to be 48 hawks based on extensive surveys using a density of .001 hawks/ha. as given by Morrison *et al.* (1994). Island wide extensive road surveys had an overall estimate of 800 hawks. This is half that of intensive survey estimates of 1600 birds per 400,000 ha (1,000,000 acres) of suitable habitat (Morrison *et al.* 1994). Griffin's estimate of the `Io population in 1985 was 2700 total hawks. This estimate was extrapolated from intensive surveys assuming 343,000 ha (857,500 acres) of available `Io habitat and a 53.5% overlap in home range. The methods, habitat analysis, and discussion of results for these Hawaiian hawk population surveys are discussed in detail by Morrison *et al.* (1994).

Although `Io appear to be very adaptable to foraging in many diverse habitats including agricultural and residential areas, their nesting habitat and susceptibility to disturbance during the breeding season appears to be a limiting factor (Griffin 1985). `Io, like many raptors, will abandon their nest if disturbed (especially before eggs are laid or during early stages of incubation). The availability of undisturbed nesting areas was not addressed in the various population surveys. `Io exhibit strong fidelity to nesting territories and according to Griffin (1985), "vacancies" in available breeding territories and available mates are few. He observed large numbers of immature `Io in agricultural areas during the winter and fall. Younger birds (without their own territories) appeared to be tolerated by resident `Io during the non-breeding season (Griffin 1985). Although many `Io were sighted in agricultural areas during our surveys, the number of breeding hawks could not be determined outside of the breeding season.

POTENTIAL IMPACTS OF THE PROPOSED GEOTHERMAL DEVELOPMENT

By addressing the major impacts that disrupt `Io populations, steps to minimize the effects of proposed geothermal development can be implemented. Conservation measures necessary to protect hawks have been incorporated into our recommendations. Potential impacts on Hawaiian hawks could result from the following disturbances:

1) Land clearing and road building for geothermal project operations

Land clearing disturbs breeding and nesting pairs of `Io. Removal of nest and perch trees during land clearing would be detrimental. Forest clearing has been observed to result in nest abandonment (Griffin 1985).

Geothermal project proposals indicate development will clear 916 ha (2,263 acres) out of 55,250 ha (136,520 acres) of project land. A 9 m (30 ft) access road of 12 km (7.5 miles) long and an unspecified number of secondary roads are proposed. Additionally there will be clearing for transmission lines, conductor string sites, and powerlines (Towill 1982). Habitat destruction alone would be expected to negatively impact 1-5 hawks. Construction activities will likely decrease the available number of nest trees and create disturbances to breeding due to geothermal plant construction and operation (drilling, emissions, land clearing).

2) Emissions and noise

Noise and emissions from geothermal operations may be potentially disruptive or harmful to birds. However, we are not aware of any studies that quantify these effects on the Hawaiian Hawk. Operation of drilling equipment, power plant cooling towers, and bright light sources used for all night operations of the geothermal plant may cause some degree of disturbance to nesting birds.

MANAGEMENT RECOMMENDATIONS

In order to minimize the risks to `Io populations, recommended mitigation measures include:

1) Avoidance of areas previously used for nesting. `Io will reuse old nests for many seasons. Pre-surveys of construction sites, roadways, and secondary roads for old nests and hawk sightings should be conducted prior to any clearing or construction activities with a buffer of at least 500 m (1,640 ft) maintained at established and potentially active nests.

2) Time construction outside of the breeding season. Construction, drilling, installation of transmission lines, and road construction should occur between October and February for minimum impact to breeding birds.

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Table 1. Summary of 'Io detections during surveys in the Puna District conducted between December 20, 1993 and January 27, 1994.

Date	Area	Time	Distance from observers (meters)	Detection type[1]	Comments
Dec. 20	Route 132 mm 7	1437	30 80 35	V V A	3 birds observed; one perched on telephone wire
Dec. 22	Kaohe Homesteads 2 mi from rte 130	1428	500	V	
Jan. 4	Route 130 .2 mi N. of mm 10	931	40	V	
	Heiheiahulu Road .5 mi up road to puu	1140	150	A	
	Pahoa/Pohoiki Road 1.2 mi from Rte 137	1427 1427	9 30	A/V V	2 birds detected
	Route 132 mm 5	1515	3220	V	2 birds detected
		1524	45	A/V	
Jan. 10	Route 11 2 mi s. of S. Glenwood Road	1131 1130	1000 70	V A	2 'io detected
	Beach Road 2 mi S of Makuu	1538	60	V	2 birds observed; one perched in hala
Jan. 11	Route 130 mm 9.8	938	200	A/V	
	mm 16	1108	20	V	Flew into an *Albizia* tree
	Pahoa/Pohoiki Road 1.2 mi from Rte 137	1416		A	Vocalizations faint and distant

Table 1. Continued.

Date	Area	Time	Distance from observers (meters)	Detection type[1]	Comments
Jan. 18	Beach Road 2 mi S of Makuu Rd	1050	80	V	
	Puna Trail 3 mi N of Rte 130/137 intersection	1050	45	A/V	
Jan. 19	Pahoa/Pohoiki Road 1.2 mi from Rte 137	1029	50	A/V	
Jan. 25	Route 130 mm 18	1048	50	V	
	Route 130/137 intersection	1036	1610	V	
Jan. 27	Corner of Akala & Makuu roads	941	20	V	Perched on telephone wire over Beach Rd
	Puna Trail 3 mi N of Rte 137/132 intersection	835	35	V	Perched on tall snag

[1] A=auditory detection; V=visual detection

Table 2. Summary of 'Io density estimates (Morrison et al. 1994) calculated by program "DISTANCE", from extensive transect data collected in the Puna District and islandwide from December 20, 1993 - January 28, 1994 [1]

	Upper Puna transects	Lower Puna transects	Combined Puna Transects	Island[2] wide transects
Tot. no. of times each point was sampled	105	100	205	438
No. of survey points	21	20	41	137
No. of Io detections	9	18	27	76
Density estimate (birds/ha)	.001	.002	.001	.002
Standard error	.0006	.0007	.0005	.004
Coefficient of variation %	53.0	45.7	35.6	19.1
95% Confidence intervals	.0004 -.003	.0007- .004	.001- .003	.001-.003
Degrees of freedom	25	30	60	200
Detection probability	.02	.04	.18	.03
No. of birds expected to be observed/point	.09	.18	.13	.17

[1] For explanation of "DISTANCE" program estimations see Morrison et al. 1994.

[2] Areas surveyed extensively within the districts of North and South Kona, North and South Kohala, Hamakua, North and South Hilo, Puna, and Kau.

Table 3. Summary of incidental 'Io sightings in Puna for August 1993 - January 1994.

Date	Location	Time	Habitat Description[a]
Sept.1 Sept.22	Heiheiahulu	0600 0645	open canopy ohia-uluhe forest with exotic grasses and shrubs fragmented by pasture
Dec.15 Dec.15 Dec.16 Dec.16	Iilewa crater	1200 1200 1400 1400	interface of wet closed canopy ohia-uluhe forest and lava flow with pioneer vegetation
Jan.4	Kahakaī Road (MM 1.6)	0946	open canopy mixed ohia-uluhe forest with exotic trees, shrubs and grasses
Dec.14	Kahaualea NAR (Tr. 371, St. 6)	0935	wet native mixed ohia forest with native under story
Dec.12	Kalapana	1738	mixed lowland forest adjacent to lava flow with pioneer vegetation
Dec.9 Jan.10	Kaloli RD (Near RT 130 MM 4.6)	1424 1424	fragmented, residential with open ohia/uluhe and exotic shrubs, grasses, and trees
Aug.25 Jan.21 Jan.21 Jan.25	Kapoho Crater (RT 132 MM 7)	1200 1027 1043 1336	mixed exotic lowland forest surrounded by lava flow and agricultural land
Dec.7	Nanawale Forest Reserve	1200	open ohia/uluhe forest with native and exotic shrubs, exotic grasses adjacent to old agricultural land
Dec.21	Pahoa/pohoiki Road (Oneloa ahupa'a)	1000	open ohia/uluhe, native shrubs, exotic shrubs and grasses
Aug.23 Jan.21	Pawai Crater	1245 0736	large pit crater with mixed ohia/uluhe and exotic trees
Dec.27	Puhala Street	1322	open canopy mixed ohia/uluhe forest with exotic trees, shrubs, and grasses
Dec.20 Jan.18	Puna Trail	1404 1102	mesic mixed lowland exotic forest

Table 3. Continued.

Date	Location	Time	Habitat Description[a]
Aug.28 Jan.21	Puu Honuaula	1252 0807	small cindercone with mixed exotic vegetation surrounded by agriculture; some ohia near Puna Geothermal Venture
Aug.23	Puu Kaliu	1620	wet closed canopy mixed ohia forest with exotic shrubs and grasses
Aug.10 Aug.31 Sept.9 Sept.9 Sept.10 Sept.10 Sept.14 Sept.14 Sept.23 Sept.30 Sept.30 Oct.5	Puulena Crater	1910, 1648, 1743, 1840, 0601, 1608, 1608 1735 0559, 1757, 1800, 1824	large pit crater with mixed native and exotic vegetation; ohia, uluhe, hala, kukui
Nov.19	Puu O'o	1328	new lava adjacent to native wet forest
Sept.1 Jan.27	Puu US Cellular Tower (Route 132 MM 4)	1835 0802	small cindercone with mixed exotic vegetation, a few ohia trees surrounded by agriculture
Jan.4	Route 11 MM 9 (Volcano HWY)	1157	fragmented commercial/residental/ agricultural, mostly exotic trees
Jan.10	Route 11 MM 22 (Volcano HWY)	1700	open canopy ohia/uluhe forest
Jan.18	Route 11 MM 27 (Volcano HWY)	0735	closed canopy ohia forest
Oct.15	Route 130 MM 7 (Keaau-Pahoa RD)	1630	open ohia/uluhe with exotic trees, exotic shrubs, and exotic grasses

Table 3. Continued.

Date	Location	Time	Habitat Description[a]
Sept.03	Route 130 MM 15-16	0757	interface of agricultural land,
Sept.20	(Keaau - Kalapana	1715	fragmented open canopy ohia forest
Dec.2	RD)	0810	with exotic understory, and lava flow
Dec.9		1153	with pioneer vegetation
Dec.9		1212	
Dec.12		1725	
Dec.22		1308	
Dec.22	Route 130 MM 18 (Keaau-Kalapana RD)	1227	mesic mixed ohia forest with exotic understory
Jan.21	Route 132 MM 6 (Kapoho RD)	0921	scattered exotic trees, lava flow with pioneer vegetation and adjacent agricultural land
Dec.9	Route 137/Pohoiki	1442	mesic forest with exotic trees and
Dec.9	(Kapoho Beach RD)	1442	exotic understory

Total incidental hawk detections = 56 for Aug. 1, 1993-Jan.27, 1994. These detections were incidental to forest bird, seabird, Hawaiian hoary bat, botanical, and 'Io playback surveys.

[a]Terms used to describe habitat types surveyed in the Puna District are defined in Appendix 1.

Appendix 1. Key for site descriptions (adapted from Char and Lamoureux 1985; Wagner *et al.* 1990).

Agricultural (Agr) Land - includes sugar cane, papaya, macnuts, banana, fallow fields, pasture land, and the roads associated with farming activities

Dry - receives less than 1200mm rainfall annually

Mesic - an area that is neither very wet or very dry, receives 1200 - 3,800mm annually

Mixed Lowland Forest - varied mosaic of plant associations. Usually a fragmented mixture of exotic trees with some native trees. The canopy height can vary from a low stature to tall. The understory varies depending on the nature of past disturbances and the amount of canopy cover

Ohia Forest (Woodland) - dominantly native ohia (*Metersideros sp.*) overstory

Ohia/Uluhe - dominantly native; ohia tree canopy with an uluhe (*Dicranopteris* sp.) understory

Pioneer Lava Flow - recent lava flow with pioneer vegetation, usually young ohia (*Metersideros collina*) and sword fern (*Nephrolepis multiflora*) and lichens (*Stereocaulon vulcani*)

Scrub - often occurs on rough lava, and areas that are frequently disturbed or previously cleared, usually dominated by exotic species. Most vegetation is 1- 6 m tall.

Wet - area that receives greater than 2,500mm rainfall annually.

Appendix 2. Vegetation associations for surveys of upper Puna

Transect Name	Sta #	Vegetation Association
Jungle King	1	*W:O3Me/O2Me,nt(mf,tf,xg,gf) /nt=Psychotria spp /mf=Dicranopteris linearis /tf=Cibotium spp /xg=Andropogon virginicus,Arundina graminifolia,other mix exotic grass /gf=Nephrolepis spp*
Jungle King	2	*W:C2-3Me(mf,xs,xg,gf) /mf=Dicranopteris linearis /xs=melastoma,Mangifera indica /xg=Melinis minutiflora,Arundina graminifolia,Impatiens wallerana /gf=Lycopodium spp*
Rte 11	1	*W:C3-4xt(xs,xg) bordering open pasture /xt=Eucalyptus spp,Albizia falcataria,Phyllostachys nigra /xs=Melastoma,Psidium cattleianum /xg=mixed exotic grass*
Rte 11	2	*W:4*xt/2-3xt,Me(tf,xg,xs,mf) *xt=Eucalyptus spp /xt=Pluchea,Psidium cattleianum /tf=Cibotium spp /xg=Andropogon virginicus,other mix exotic grass*
Rte 11	3	*W:D3xt,Me(xs,xg)bordering open pasture & residential area /xt=Eucalyptus spp,Psidium cattleianum,Cocos nucifera, /xs=mixed exotic shrubs /xg=mixed exotic grasses*
Rte 11	4	*W:D3xt bordering reidential area & fallow sugar cane fields. /xt=Albizia falcataria,Psidium cattleianum*
G St	1	*W: O2Me,xt(xs,tf,xg,mf,gf) Residential /xt=Eucalyptus spp /xs=Psidium cattleianum,Cordyline fruticosa,Zingiberaceae spp /tf=Cibotium spp /xg=Andropogon virginicus,Tibouchina herbacia /mf=Dicranopteris linearis /gf=Nephrolepis spp*
G St	2	*W:O2Me(mf,xg,xs) /xg=Arundina graminifolia,Andropogon virginicus /xs=Cocos nucifera,Melastoma spp /mf=Dicranopteris linearis*
G St	3	*W: O1-2Me(mf,xs,xg,gf) /mf=Dicranopteris linearis /xs=Pluchea,Melastoma,Psidium cattleianum /xg=Andropogon virginicus,Arundina graminifolia,other mixed exotic grass /gf=Nephrolepis spp*
9 St	1	*W: S-O2Me(xg,xs,Me) Residential /xs=Melastoma,Pluchea /xg=Andropogon virginicus,Arundina graminifolia,Melinis minutiflora*

Appendix 2. Continued

Transect Name	Sta #	Vegetation Association
9 St	2	*W: S2Me(mf,xs,xg,gf)bordering a large dense Ohia stand in the distance. /mf=Dicranopteris linearis /xs=Melastoma,Psidium cattleianum /xg=Andropogon virginicus,Arundina graminifolia,Melinis minutiflora /gf=Lycopodium spp,Nephrolepis spp*
Shipman field	1	*W: C2-3xt(xg,xs)bordering open playing field xt=Albizia falcataria,Pithecellobium saman,Melochia umbellata,Persea americana,unk palm /xg=Melinis minutiflora,Panicum maximum,Impatiens wallerana,Tradescantia linearis,Wedelia /xs=Melochia umbellata*
Rte 130	1	*W: O2Me,xt(ns,xs,mf,xg,gf) Residential /xt=Cecropia obtusifolia,Ficus microcarpa,Psidium cattleianum /ns=unk spp /xs=luchea spp,Melastoma spp /mf=Dicranopteris linearis /xg=Andropogon virginicus,Arundina graminifolia, /gf=Pityrogramma calomelanos*
Rte 130	2	*W: S2Me,xt(xg,xs,mf) Residential/Cleared area with native perennials /xt=Cecropia obtusifolia,Banyan,Psidium cattleianum,Cocos nucifera,Casuarina glauca,Araucaria heterophylla /xg=mixed exotic grasses /xs= unk spp /mf=Dicranopteris linearis*
Kaholi	1	*M: O2Me,2xt(xs,xg,gf) Residential /xt=Cecropia obtusifolia,Trema orientalis /xs=Pluchea spp,Cecropia obtusifolia,Melastoma spp, Psidium cattleianum,Lantana spp /xg=Andropogon virginicus,Splathoglottis plicata,Arundina graminifolia,Mimosa pudica,other mixed exotics /gf=Nephrolepis spp*
Kaholi	2	*M: C/O2-3Me,2-3xt(xs,gf,xg) xt=Cecropia obtusifolia /xs=Lantana spp,Macaranga mappa,Clusia rosea,Melastoma spp,Psidium cattleianum,Psidium guajava /xg=Mimosa pudica,Andropogon virginicus,Arundina graminifolia,Agoratum coryzoides /gf=Nephrolepis spp,Microsorium scolopendrium*
Puna Trail	1	*W: S1-2 xt(xs,xg) Residential /xt=Casuarina glauca,Hala,palms,Cecropia obtusifolia /xs=unk spp /xg=mixed exotic grasses*

Appendix 2. Continued

Transect Name	Sta #	Vegetation Association
Puna Trail	2	*W: S2-3xt dense clusters (xg,xs) understory very dense /xt=Pandanus tectorius,Mangifera indica,Cecropia obtusifolia /xg=Andropogon virginicus,Arundina graminifolia,other mixed exotics /xs=Psidium cattleianum,Psidium guajava,Pluchea spp.Melastoma,Cordyline fruticosa*
Puna Trail	3	*M: C2-3xt(xg,xs) Residential /xt=Cocos nucifera,Pandanus tectorius /xg=mixed exotic grasses /xs=mixed exotic shrubs*
Puna Trail	4	*M: S2-3xt(xg,xs) understory very dense /xt=Pandanus tectorius,Mangifera indica,Cocos nucifera,Cecropia obtusifolia /xs=Psidium cattleianum,Pluchea spp /xg=Panicum maximum,unk. pea family,Andropogon virginicus,Pasballum spp,Melinis minutiflora*
Puna Trail	5	*W: D4xt/2xt(xg,gf,xs) /xt=Mangifera indica,Cecropia obtusifolia,Albizia falcataria,Melochia umbellata,Cocos nucifera,Psidium cattleianum /xg=Oplismenus hirtellus,Impatiens wallerana /xs=Melochia umbellata,Persea americana,Zingiberaceae spp /gf=Nephrolepis spp*

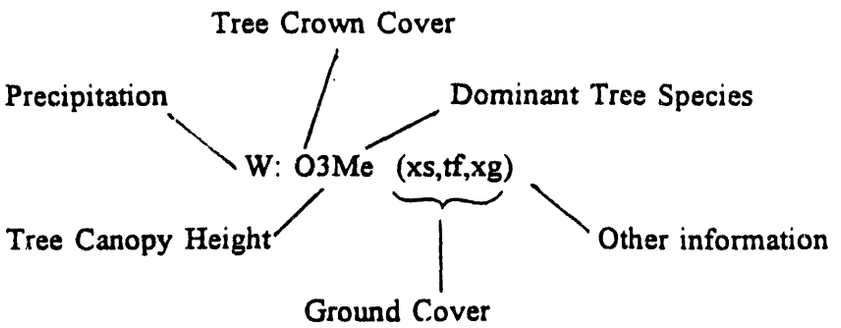
Appendix 3. Vegetation associations for survey route of lower Puna

Transect	Sta.	Vegetation Association
Ainaloa	1	*W: S1xt,Me(xs,xg,gf) xt=Cocos nucifera,Cecropia obtusifolia /xs=Melastoma spp.,Mimosa pudica /xg=Andropogon virgiicus,Arundina graminifolia Spathoglottis plicata /gf=Lycopodium spp,Pityrogramma calomelanos*
Rte 130	1	*W: S1xt(xs,xg) Resid/Ag.land, bordering Metrosideros polymorpha stand /xs=Lantana spp,Melastoma spp,Cordyline fruticosa /xt=Cocos nucifera*
Kahakai	1	*W: O2xt,me(xg,xs,,gf) xt=Melochia umbellata,Albizia falcataria,Cecropia obtusifolia,Cocos nucifera /xs=Lantana spp,Mimosa pudica /xg=Arundina graminifolia,Melinis minutiflora,Andropogon virginicus,Spathoglottis plicata /gf=Nephrolepis spp*
Kaohe	1	*M: S3xt(fallow sugar cane field)/D3-4Me approx 150 meters away /xt=Albizia falcataria*
Rte 130	2	*W: Fallow cane field S2xt(xg,gf,xs) xt=Cecropia obtusifolia,Albizia falcaria /xg=Melinis minutiflora,Robus rosiflolius /xs=Mimosa pudica /gf=Nephrolepis spp*
Rte 130	3	*W:D3xt/C3-4Me(gf,xg,mf,xs) small open area /xt=Psidium cattleianum,Melochia umbellata,Araucaria heterophylla /gf=Nephrolepis spp /mf=Dicranopteris linearis /xs=Melastoma spp,Hibiscus spp*
Rte 130	4	*W: O2Me,xt(xg,gf,xs) Pioneer lava field /xt=Albizia falcataria /xg=Andropogon virginicus,Arundina graminifolia /xs=Pluchea spp /gf=Nephrolepis*
Heiheiahulu	1	*W: O3Me(mf,xg,xs,gf) /mf=Dicranopteris linearis /xg=Andropogon virginicus,Arundina graminifolia,unk.sedge /xs=Lantana spp,Melastoma spp,Pluchea spp /gf=Pityrogramma calomelanos,Lycopodium spp*
Rte 130	5	*M: O3Me(nv,xs,xg,mf)bordering C4Me stand. /nv=Cuscuta sandwichiana /xs=Psidium guajava,Pluchea spp /xg=Arundina graminifolia ,Andropogon virginicus /mf=Dicranopteris linearis*
Rte 137	1	*D: O2-3xt(xg,xs) xt=Mangifera indica,Cocos nucifera,unk. /xg=Andropogon virginicus,unk.spp /xs=Prosopis pallida*
Rte 137	2	*M: O1Me(ns,gf,xg,xs) Coastal /ns=Scaevola sericea /gf=Nephrolepis spp /xs=Lantana spp,Psidium cattleianum*
Rte 137	3	*D: O2-3xt(xs,gf,xg) Coastal lava field with pioneer vegetation xt=Casuarina glauca,Cocos nucifera /xs=Pluchea spp /xg=mixed unk. /gf=Nephrolepis spp*
Rte 137	4	*M: C2-3xt,Me(ns,xg,xs,) Coastal, dense understory /xt=Mangifera indica,Pandanus tectorius,Aleurites moluccana /ns=Scaevola sericea /xg=Wedelia trilobata,unk. /xs=Convolvulaceae spp,Morinda citrifolia,Cocos nucifera*

Appendix 3. Continued.

Transect	Sta.	Vegetation Association
Rte 137	5	*M: O3-4xt(xs,xv,xg,gf) Coastal, dense understory /xt=Cocos nucifera,Mangifera indica,Cecropia obtusifolia /xs=Cocos nucifera,Cecropia obtusifolia, /xv=unk /xg=Impatiens wallerana /gf=Microsorium scolopendrium*
Rte 137	6	*M: S4*xt/C2-3xt,Me(xs,xg,gf) *xt=Cocos nucifera /xt=Mangifra indica,Psidium cattleianum,Cocos nucifera,Melochia umbellata,Albizia falcataria,Pandanus tectorius /xs=Psidium cattleianum,Psidium guajava,Cocos nucifera,Melochia umbellata,Mimosa pudica /xg=Melinis minutiflora,other unk.spp /gf=Microsorium scolopendrium*
Pohoiki	1	*W:C3xt(gf,xg) vegetation borders roadsides only, the remaining habitat is papaya fields /xt=Mangifera indica,Cecropia obtusifolia, Pandanus tectorius/gf=Nephrolepis spp /xg=Oplismenus hirtellus,mixed unk.*
Pohoiki	2	*W: 3-4*xt/C2-3Me,xt(xs,mf,xg,) *xt=Albizia falcataria /xt=Melochia umbellata /xs=Psidium cattleianum,Melochia umbellata /mf=Dicranopteris linearis /xg=Wedelia trilobata,Arundina graminifolia,impatiens wallerana*
Rte 132	1	*W: C1-2Me/S3-4xt(xg,xs) adjacent to papaya field xt=Albizia falcataria /xg=Andropogon virginicus,Arundina graminifolia,Spathoglottis plicata,other mixed exotics /xs=Melastoma spp, Pluchea spp*
Rte 132	2	*M: S1Me,xt(xg,gf) Lava field w/ pioneer vegetation/small stand C4xt xt=Ceropia obtusifolia,Albizia falcataria /C4xt=Albizia falcataria /xg=Andropogon virginicus,Arundina graminifolia,mixed unk /gf=Nephrolepis spp*
Rte 132	3	*M: 03-4xt(xs,xg,gf)bordering agricultural land /xt=Casuarina glauca,Mangifera indica,Cecropia obtusifolia,Cocos nucifera,Albizia falcataria /xs=Pluchea spp,Schinus terebinthifolia,Psidium cattleianum /xg=mixed exotic grasses /gf=Nephrolepis spp*

Appendix 4. Key to vegetation associations symbols



Tree Crown Cover
D = dense; >85%
C = closed; >60-85%
O = open; 15-60%
S = scattered; <15%

Tree Canopy Height
1 = 3-5 meters tall
2 = >5-10 meters tall
3 = >10-25 meters tall
4 = >25 meters tall

Vegetation Abbreviations

Me = 'Ohi'a	tf = tree fern	Ch = olapa	
mf = matted fern	nt = native tree	Il = Ilex	
ng = native grass	gf = ground fern	Psc = strawberry guava	
ns = shrub	xg = exotic grass	Ps = Psychotria	
nv = native vine	xv = exotic vine		
xs = exotic shrub	rs = rainforest shrub		

Precipitation
W = wet
M = mesic
D = dry

Animal damage:

tr = trampling	gr = grazing
bl = distinct browsline	gd = girdling
ff = fern frond feeding	rb = rubbing damage
br = noticeable browsing	dg = digging

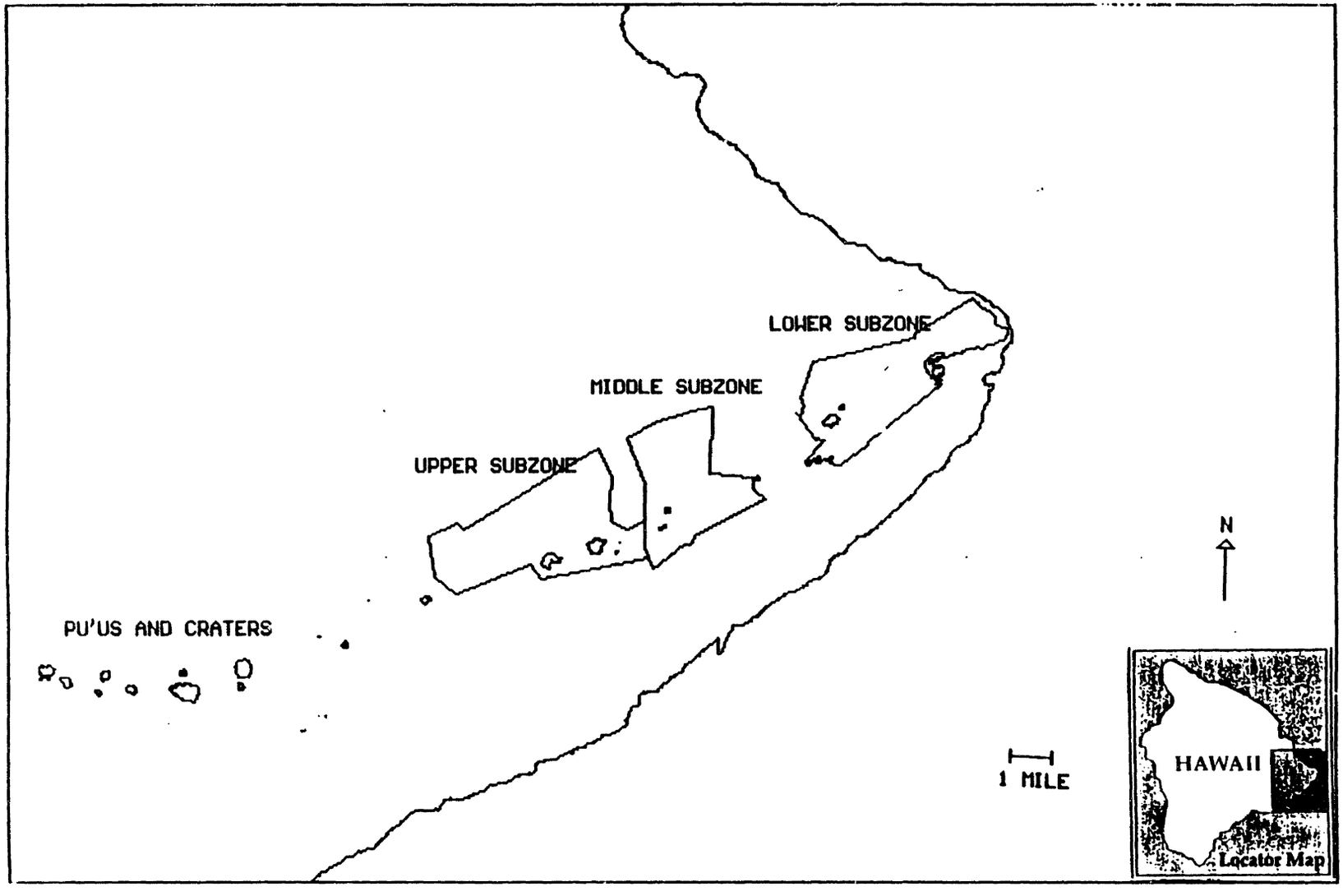


Figure 1. Geothermal subzones: proposed project areas.

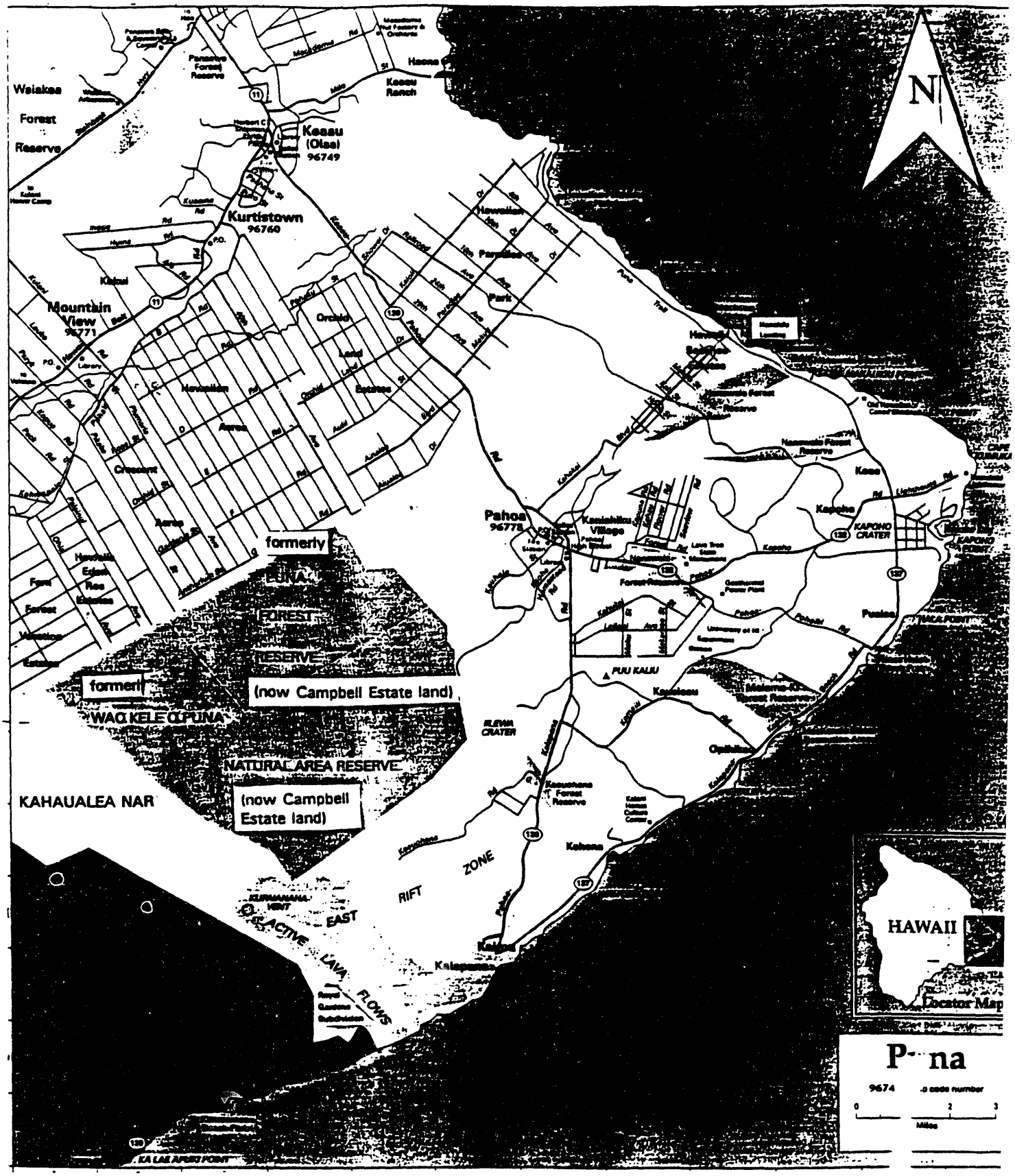


Figure 2. Reference map of the Puna district adapted from Eureka (1993).

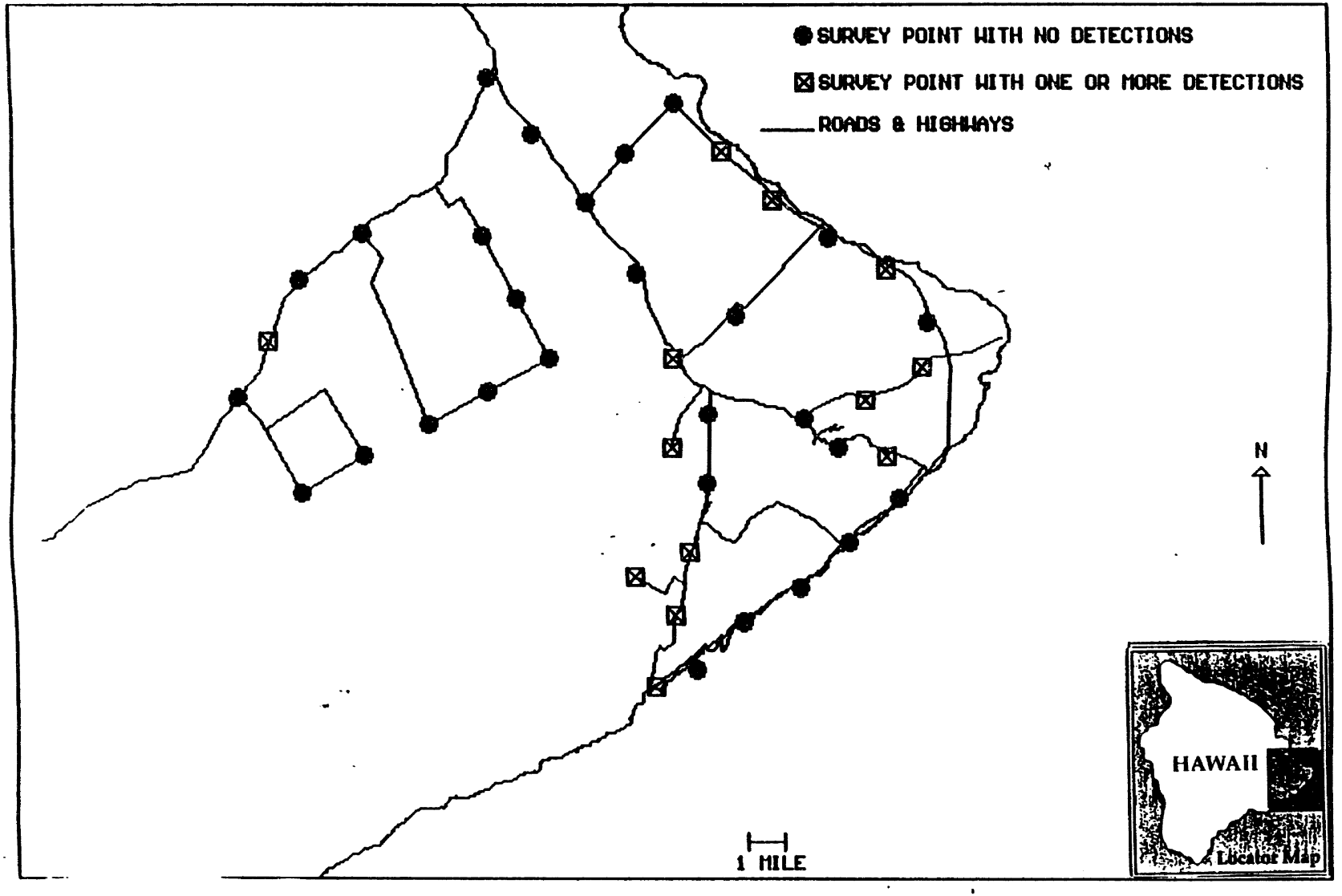


Figure 3. Locations of 'Io detections along road transects surveyed December 1993 - January 1994.

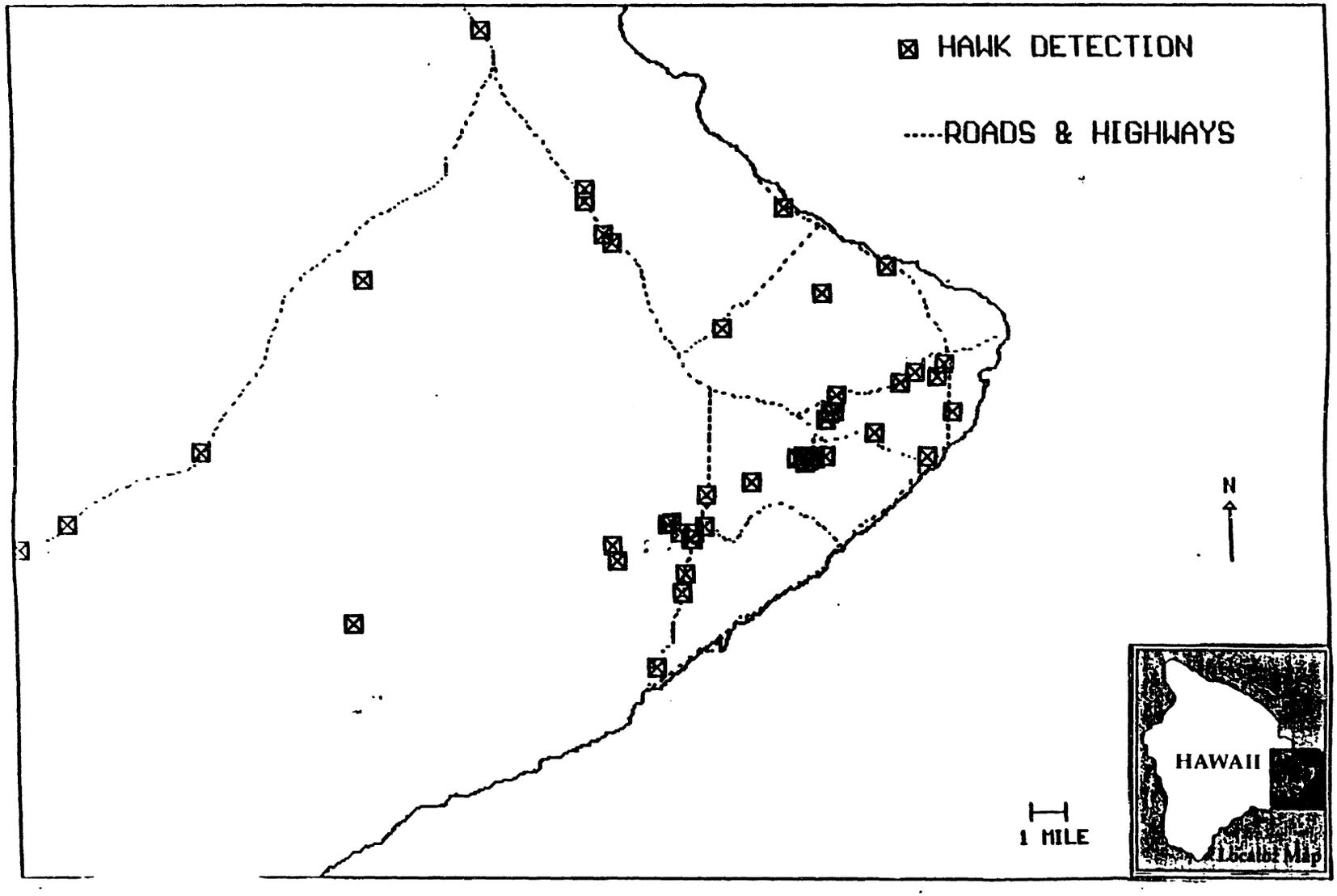


Figure 4. Locations of incidental 'Io sightings in Puna August 1993 - January 1994. A total of 56 hawk detections were made.